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Total selectivity of a commercial cod trawl with and without a grid mounted: grid and codend selectivity of north-east Artic cod

Cecilie Kvamme*, Bjørnar Isaksen

Institute of Marine Research, P.O. Box 1870, Nordnes, N-5817 Bergen, Norway

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Abstract

The sorting grid was introduced in the Barents Sea gadoid fishery in 1997. During an experiment west of Bear Island in summer 2001, the total selectivity of a commercial cod trawl with a single grid mounted (grid selectivity × codend selectivity) was compared with that of the same trawl without a grid (codend selectivity). This is the first comparison of the selectivity of these gears during a single experiment. The results showed a surprisingly similar selection range for grid and codend selectivity: around 10 cm. With a grid mounted, the 50% retention length of the trawl rose by about 4 cm. The results demonstrate that catch rate or catch size may influence both 50% retention length and selection range.

Keywords: Size selectivity; Trawl; Grid; Codend; Cod; *Gadus morhua*

1. Introduction

The north-east Arctic cod (*Gadus morhua*) stock is an economically important stock, with landings of more than 400 000 tonnes in 2000 (Anon, 2002). To optimise the yield it is important to exploit the growth potential of the fish by minimising fishing pressure on juveniles (Beverton and Holt, 1957; Armstrong et al., 1990). In a trawl fishery this can be achieved by closing areas or seasons, by changing codend mesh size or mesh shape or by introducing sorting devices such as grids and windows (Alverson et al., 1994; Hall, 1996; Alverson, 1999).

In the Barents Sea, adult and juvenile gadoids are mixed, and in order to avoid the widespread closure of fishing areas there is a need for trawl gears that sort out the juveniles. With sharply defined selection, most juveniles can escape without the cost to the fishery of high rates of loss of fish of marketable size. Stock managers therefore prefer gears with steep selection curves. Selection experiments performed during the early 1990s showed that the selection characteristics of the sorting grid Sort-X (Larsen and Isaksen, 1993) were better, i.e. the selection was sharper than in codend meshes (Isaksen et al., 1990). On the basis of these experiments and experiments showing a survival of nearly 100% for escaping cod (Soldal et al., 1993), trawlers with sorting grids were allowed access to closed areas in the Barents Sea in the early 1990s. The grid was made mandatory in the Barents Sea in 1997, and further south to 62°N in 2000 (Fig. 1). In the trawl fishery for groundfish in the Barents Sea, a minimum codend mesh size of 135 mm and a sorting grid (Sort-X,[1] Sort-V[2] or single grid[2]) with a minimum bar distance of 55 mm are currently compulsory.

* Corresponding author. Tel.: +47-55-238500; fax: +47-55-238531.
E-mail address: cecilie.kvamme@imr.no (C. Kvamme).

[1] Consists of two metal grids.
[2] Consists of one metal grid.

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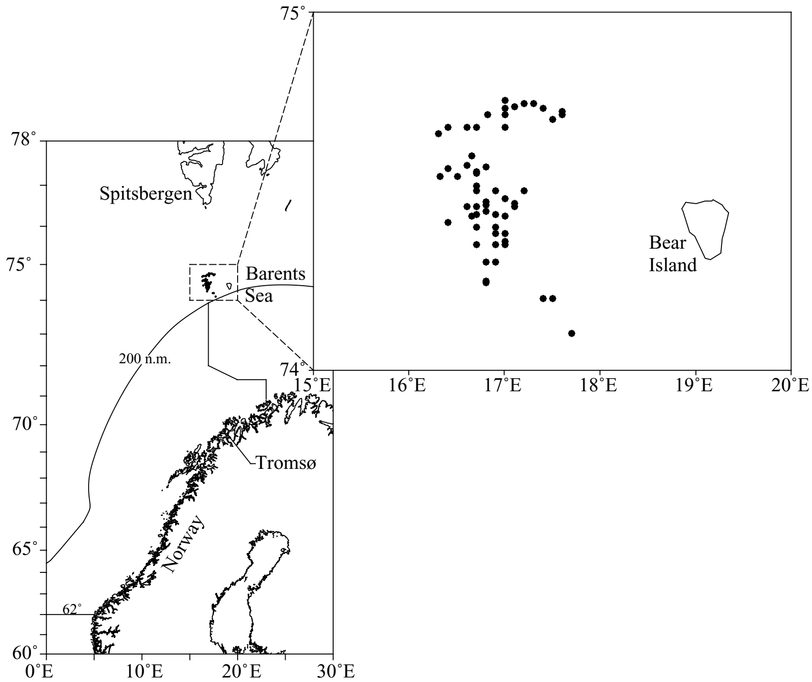

Fig. 1. The area west of Bear Island (in ICES area IIb) where the experiments were carried out, and the geographical positions of all trawl hauls in the selection experiment. The availability of cod decided the haul position. The 200 nautical mile exclusive economic zone along the Norwegian coast is indicated. The northern (plus the rest of the Barents Sea and an area around Spitsbergen) and southern parts of the zone correspond to the parts of this economic zone where sorting grids were made compulsory in 1997 and 2000, respectively.

The selection profile of a 135 mm diamond mesh codend was studied in 1989 (Isaksen et al., 1990), but the codend material has changed since then and this may have altered its selection characteristics. Sorting grid selection has been studied several times (e.g. Larsen and Isaksen, 1993), but to the best of our knowledge, the total selection of the cod trawl with a grid mounted has never been studied. A study of both the total selection for north-east Artic cod by a trawl without a grid (codend selection) and the same trawl with a grid (grid selection × codend selection) was thus needed. The size selection of fish may be affected by factors related to the gear, fish, environment and vessel (Wileman et al., 1996), and when the selection characteristics of different gears are being compared it is thus important to keep all factors but gear differences as constant as possible. The two gear types were therefore studied during the same experiment, with the same vessel and method, within the same area and during the same period of time.

2. Materials and methods

The experiments were performed on board the chartered 50.75 m commercial trawler “Anny Kræmer”, built in 1980 and equipped with a 2400 bhp engine. In order to obtain representative estimates of the selection parameters, it is important to fish on a population with a high proportion of individuals of the size for which the selection process is intended (Polet and Redant, 1999). The experiments were carried out from 21 June to 3 July 2001 in ICES area IIb west of Bear Island (Fig. 1)—an area with normally good access in summer to cod with a high admixture of fish below the minimum landing size (MLS = 47 cm). Light intensity influences the capture process (Wardle, 1989),

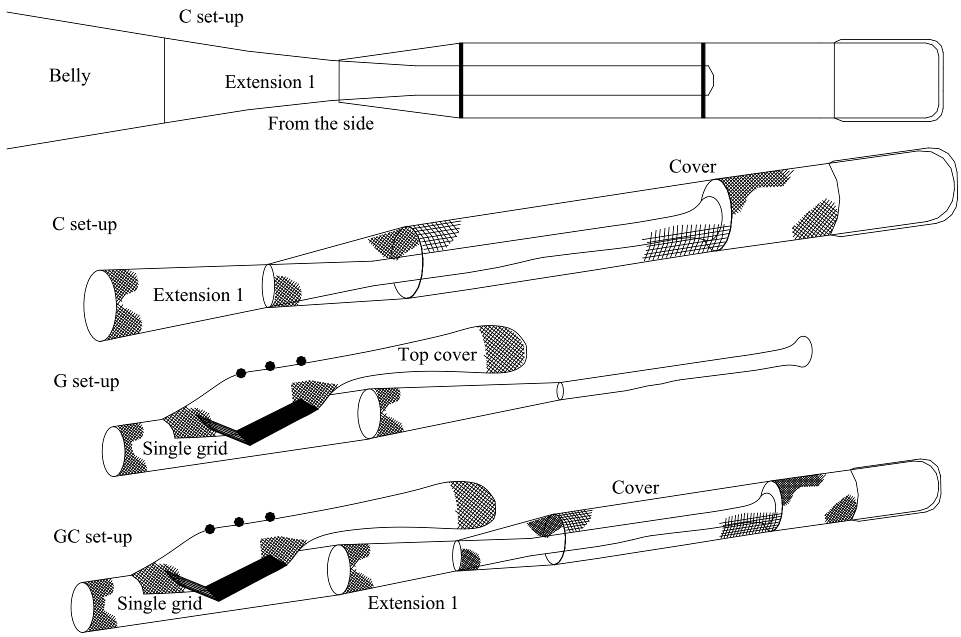

Fig. 2. The experimental setups. Setup C: a standard commercial trawl (Table in the Appendix A) without grid, rigged as before the grid was introduced, with a 90-mesh extension piece in 135 mm inside mesh size between the belly and the codend. The hooped cover was held open by two rings (Table in the Appendix A) positioned in front of and just behind the codend. The front and rear part of the cover was made from diamond meshes, whereas the part between the rings was made up of square meshes to prevent sag in this netting. Setup G: a single grid system (modified Sort-V, Table in the Appendix A) was installed in an extension piece between the belly and the same extension and codend as used in setup C. A top cover was mounted over the grid release area as described in Wileman et al. (1996). A small-meshed blinder (Table in the Appendix A), used inside the main codend, was made 30% wider than the codend itself to prevent too heavy load on this thin-twined and small-meshed netting. Setup GC: grid and top cover rigged as in setup G. The hooped cover was mounted as in setup C.

and the small difference in day and night light intensities during the polar summer ensured as similar light conditions as possible for the various hauls.

Three different selectivity setups (Fig. 2, Table in the Appendix A) were run during the experimental period.

- C: covered codend and no grid mounted. Codend (mesh) selection only.
- G: grid mounted with top cover (Wileman et al., 1996) over fish outlet and blinded codend. Grid selection only.
- GC: grid mounted with top cover over fish outlet and covered codend. Grid and codend (mesh) selection studied simultaneously, but separately.

The covered codend method (Wileman et al., 1996) was chosen for these experiments. An advantage of this method is that a selection curve can be estimated directly from each haul, as the number of fish entering the codend mouth is what defines the experimental population (Wileman et al., 1996). The disadvantages are mainly related to the handling of the hooped cover, but the calm weather during this experiment minimised this problem. In addition, the cover may affect fish behaviour or gear performance. The alternative would be the trouser trawl method (Wileman et al., 1996), but a study of both the grid and codend selection simultaneously during a single haul would have required some kind of cover in any case, and the problems would thus have been the same as with the covered codend method. Additional problems such as different drag between the codends and problems with convergence of data to selection curves might have been added. Madsen and Holst (2002) found no significant differences between the covered codend method (with a kite cover) and the twin trawl method as far as estimated selection parameters were concerned. We therefore feel confident

Table 1
Hauls included in the analysis of the selection characteristics for cod of an Alfredo no. 3 trawl (with 135 mm diamond mesh codend) with and without grid

Experimental setup	Series	Hauls	No. of hauls	Date	Haul duration (h)		
					Mean ± S.D.	Min	Max
C	1	3–11	9	22–23 June 2001	1.42 ± 0.46	1.00	2.00
GC	1	18, 19, 21–28	10	24–27 June 2001	2.46 ± 0.51	1.67	3.00
G	1	29–33, 37–40	9	27–29 June 2001	2.01 ± 0.77	1.33	3.83
GC	2	41, 45–47, 49, 50	6	29 June–1 July 2001	1.97 ± 1.06	0.50	3.50
C	2	51–59	9	2–3 July 2001	1.02 ± 0.58	0.25	2.00

The mean haul duration (h) with standard deviation (S.D.), and the shortest and longest lasting haul within each experimental setup and series are shown. Experimental setups—C: covered codend and no grid mounted. Codend selection (mesh) only; GC: grid mounted with top cover over fish outlet and covered codend. Grid and codend selection studied simultaneously but separately; G: grid mounted with top cover over fish outlet and blinded codend. Grid selection only.

that the covered codend method was adequate for this experiment.

Selectivity experiments seldom mimic commercial conditions. However, in this experiment the density of cod was sufficiently high to ensure catches of commercial size during relatively short hauls. The duration of a haul was decided by catch rate, as in commercial fisheries. The haul duration (time from when the trawl settled until start of haulback) therefore ranged from 0.25 to 3.83 h (Table 1). In addition, both vessel and crew came from a commercial fishery. The calm weather facilitated the experiment and made hauling relatively easy even when two cover nets were used (Fig. 2).

The experiments were carried out using a commercial two-panel bottom trawl of the Alfredo type. The trawl had a fishing circle of 453 meshes in 155 mm, a headline length and ground rope length of 36.5 and 19.2 m, respectively, and was equipped with a 24 in. rockhopper gear. It was rigged with 140 m single sweeps and 10 m headline extensions. A warp length from 2.5 to 2.8 times the depth was used. The gear was monitored by Scanmar sensors. In order to achieve our preferred otter board spread of about 140 m, the warp length was adjusted as required. With this otter board spread, the trawl had a vertical opening that varied between 3.5 and 4.0 m. In setups G and GC, seven pieces of float of 20 cm diameter were attached along the top of the top cover (Fig. 2) to lift the netting away from the grid outlet, mostly to allow the escaping fish to move freely back to the rear part. The top cover did not appear to be in physical conflict with the hooped cover during the GC setup (Fig. 2).

The 43 hauls (out of a total of 63) included in the analysis of the selection parameters are shown in Table 1. The remaining hauls were excluded (a) as they were test hauls where a different gear combination was tested ($n = 8$); (b) because of gear damage or malfunction of the grid ($n = 5$); (c) as the chafers were removed during filming ($n = 5$); (d) because of insufficient catches in the hooped cover ($n = 2$).

The mesh size of the codend was measured wet using both a wedge gauge (mean ± S.D.: 138.7 ± 2.9 mm) and an ICES gauge (137.2 ± 4.0 mm) on four occasions during the experiment. Each time two rows of 20 meshes were measured, starting at five meshes in front of the codline. The two rows were chosen four meshes to the left and right of the middle mesh row of the upper panel.

An underwater SIT camera was connected to a video recording unit (RS-600) and light was used in six hauls, both to assess the performance of the cover and to study fish behaviour during the selectivity process. The pictures showed that the distance between the hooped cover and the codend was satisfactory.

In six hauls a self-contained angle logger, about 15 cm long, was attached to the grid to control the grid angle. The logger produced highly variable results ranging from $22.3 \pm 2.7^\circ$ (mean ± S.D., during a single haul) to $35.3 \pm 1.4^\circ$. The mean of the GC and G setup was $31.2 \pm 4.4^\circ$ ($n = 4$) and $24.3 \pm 2.9^\circ$ ($n = 2$), respectively, indicating an influence of the hooped cover. The optimal grid angle is 25–26° (Isaksen et al., 1998).

The vessel is equipped with four completely separate fish bins in which the fish were stored until production. Fish from the hooped cover, the top cover and the codend were thus always kept in separate bins. For each part of the catch the length (total length to the nearest cm below) of all the cod or a sample of at least 200 fish were measured by an electronic length measuring board, Fishmeter.[3] The rest of the cod were counted. The weights of the catches were recorded from the boat's catch logbook.

L_{25}, L_{50} and L_{75} are the estimated lengths (cm) at which 25, 50 and 75% of the fish are retained in the gear, respectively. The selection range (SR) is the distance between L_{25} and L_{75} and is a measure of the slope of the selection curve. Estimates of these selection parameters were made from the length measurements by the following procedure. Selection curves were fitted to the individual hauls by the Share Each LEngths Catch Total (SELECT) method (Millar, 1992). The SELECT method takes account of the uncertainty in sampling the catches. For the estimation of grid selection the catch in the top cover was compared to the catch in the blinded codend (G setup) or the total catch in the codend plus the hooped cover (GC setup). The codend (mesh) selection was estimated by comparing the catch in the codend with the catch in the hooped cover (both C and GC setup). The software package CC 2000,[4] implementing the SELECT method, was used for the G and C setups. The GC setup consists of three different compartments: top cover, codend and hooped cover, and the CC 2000 software cannot yet handle more than two compartments. However, the method used was still the same as in the G and C setups. Using the SELECT method, selection curves were fitted to the data using maximum likelihood estimates (McCullagh and Nelder, 1989; Millar, 1992).

Logistic and complimentary log–log selection curve models (Wileman et al., 1996) were tested. The choice of a selection curve model was a compromise between choosing the curve with lowest deviance residuals and choosing the same curve for all the experimental setups in order to be able to compare gear constellations and setups. The logistic curve was the best compromise and was therefore chosen. The logistic curve is symmetric about L_{50}, and is given by (Frøysa et al., 2002)

$$r(l) = (1 + \exp(-4\alpha(l - l_{50})))^{-1} \quad (1)$$

[3] Produced by Scantrol, Norway.

[4] Produced by Constat, Denmark.

where $r(l)$ is retention by length (cm) and α and l_{50} are estimated parameters. For this curve

$$L_{50} = l_{50} \quad \text{and} \quad \mathrm{SR} = \frac{\ln 3}{2\alpha} \quad (2)$$

Individual hauls of the same type were combined by the EC software[4] which implements a special version of the Laird–Ware model (Laird and Ware, 1982), first introduced in the analysis of fishing gear selectivity by Fryer (1991). This model calculates an average selection curve, and may also be used to test for random and fixed effects. The model can test, for example, for possible effects of catch size as well as for differences between methods and gear types.

The total selection of the trawl gear with grid mounted, i.e. the selectivity of the combined gear, was estimated as the product of two logistic curves; the average grid selection and the average codend selection:

$$r_{\mathrm{tot}}(l) = r_{\mathrm{g}}(l) r_{\mathrm{c}}(l) \quad (3)$$

where $r_{\mathrm{tot}}(l)$ is the total retention probability of fish of length l (cm), $r_{\mathrm{g}}(l)$ the retention probability of the grid and $r_{\mathrm{c}}(l)$ the retention probability of the codend. A 95% confidence region for L_{50} and the selection range was calculated in S-plus for each compartment of the gear and setup.

3. Results

The estimated selection range, i.e. the sharpness of the selection, was about 10 cm for both grid and codend (mesh) selection, independent of setup (Table 2, Fig. 3). The estimated L_{50} values were 51.46 cm for the grid (G setup), and 49.34 and 44.72 cm for the codend in the C and GC setup, respectively (Table 2, Fig. 3). The estimated grid (G setup) and codend (C setup) selection did not differ significantly (Fig. 3). The selection ranges were similar, and the broad confidence interval of the grid's L_{50} overlapped with the codend selection. For codend selection, the L_{50} values clearly differed between the setups (Fig. 3). The estimated selection range of the grid in the GC setup stands out, as it is nearly twice as high as the other selection ranges. This estimate had to be left out, as it is very probable that the near doubling of the selection range compared to the G setup arose from methodological

Table 2
Selection parameters estimated for grid selection (single grid) and codend (mesh) selection of cod

Selection	Setup	Parameter	Estimate (cm)	S.D. (cm)	t-value	d.f.	P-value
Estimates of selectivity parameters[a]							
Codend	GC	L_{50}	44.72	0.56	79.98	50	***
		SR	10.25	0.32	32.26	50	***
	C	L_{50}	49.34	0.55	90.19	31	***
		SR	10.47	0.39	26.76	31	***
Grid	GC	L_{50}	51.46	1.59	32.28	50	***
		SR	19.27	0.99	19.37	50	***
	G	L_{50}	52.96	1.19	44.41	13	***
		SR	10.00	0.45	22.24	13	***
Methodology[b]							
Codend		$L_{50,GC}$	44.68	0.55	81.76	62	***
		SR_{GC}	10.36	0.25	41.40	62	***
		$L_{50,G}–L_{50,GC}$	4.71	0.72	6.57	62	***
		$SR_C–SR_{GC}$	–	–	–	62	n.s.
Grid		$L_{50,GC}$	51.99	1.10	47.39	44	***
		SR_{GC}	19.27	0.83	23.11	44	***
		$L_{50,C}–L_{50,GC}$	–	–	–	44	n.s.
		SR_G-SR_{GC}	−9.06	1.40	−6.48	44	***
Catch size[c]							
Codend	GC	$L_{50,catch=0}$	44.74	0.56	80.29	48	***
		$SR_{catch=0}$	9.28	0.51	18.08	48	***
		SR_{catch} (tonnes^{-1})	0.20	0.09	2.29	48	*
	C	$L_{50,catch=0}$	46.19	1.15	40.07	30	***
		$L_{50,catch}$ (tonnes^{-1})	0.97	0.33	2.99	30	**
		$SR_{catch=0}$	10.47	0.40	26.47	30	***
Grid	GC	$L_{50,catch\ rate=0}$	55.82	1.38	40.46	48	***
		$L_{50,catch\ rate}$ (tonnes^{-1} h)	−1.57	0.34	−4.68	48	***
		$SR_{catch\ rate=0}$	19.26	1.00	19.27	48	***
	G	$L_{50,catch\ rate=0}$	55.88	0.99	56.23	12	***
		$L_{50,catch\ rate}$(tonnes^{-1} h)	−0.91	0.18	−4.97	12	***
		$SR_{catch\ rate=0}$	9.94	0.42	23.82	12	***

n.s.: non-significant; d.f.: degrees of freedom.

[a] Grid and codend selection within each experimental setup. The grid and mesh selection of the GC setup was estimated simultaneously.

[b] For both grid and codend selection we explored whether there were significant differences between the experimental setups. The GC setup was used as base.

[c] For each experimental setup we investigated whether catch size influenced the selection parameters of grid and codend. Total weight of catch for all species (tonnes) was the best explanatory variable for codend selection, whereas catch rate (tonnes h^{-1}) explained more of the haul variance than total catch for grid selection. The estimate of L_{50} for a catch (rate) of X is $L_{50,\text{catch (rate)}=X} = L_{50,\text{catch (rate)}=0} + [L_{50,\text{catch (rate)}} \times X]$, and likewise for SR.

* $P<0.05$.

** $P<0.01$.

*** $P<0.001$.

problems. Haul-to-haul variation within the experimental setups was relatively small, except for the grid selection from the GC setup (Fig. 4).

Methodology may affect the estimated selection, and we therefore tested whether the experimental setup influenced the estimated selection parameters (Table 2, Fig. 5). For codend selection, the L_{50} of the C setup (49.39 cm) was nearly 5 cm higher than for the GC setup, whereas there was no difference in selection range (10.36 cm). For grid selection, there was no

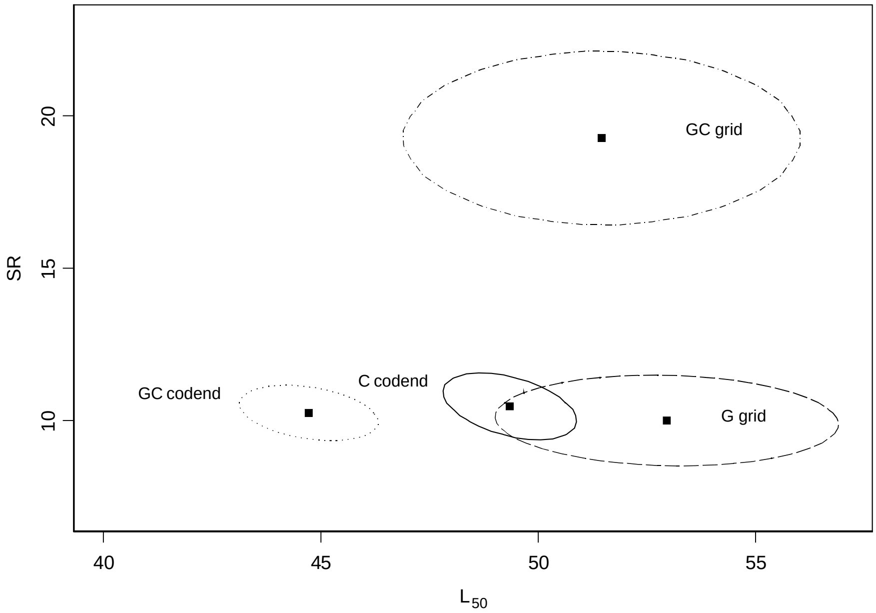

Fig. 3. The 95% confidence regions of the selection parameters for cod, L_{50} (the length in centimetres for which the estimated retention probability of the gear is 50%) and SR (selection range = $L_{75}-L_{25}$), for the grid and codend (mesh) in the different experimental setups. Overlap in these confidence regions shows that selection is not significantly different between gears (gear compartments).

difference in L_{50} (51.99 cm), whereas the selection range of the GC setup (19.27 cm) was nearly twice as large as that of the G setup.

The total selection of the trawl gear with a grid mounted was estimated as the product of two logistic curves: the average grid selection and the average mesh selection (Fig. 5). As the grid selection estimated from the GC setup has been left out because of the likely methodological problems, the total selection was calculated as the product of

(1) the average grid selection of the G setup and the average codend selection of the GC setup, and
(2) the average grid selection of the G setup and the average codend selection of the C setup.

The L_{50} of the first combination (G × GC_{codend}: 53.4 cm) was about 1.5 cm less than for the second combination (G × C: 54.9 cm), whereas the selection range was similar (G × GC_{codend}: 9.1 cm; G × C: 8.8 cm). The former combination is probably the best estimate of total selection, as the codend selection seems to be influenced by the mounting of a grid.

The haul-to-haul variance in catches was large (Table 3), with catch rates ranging from 315 to 12 488 kg h^{-1}. The catch rate increased somewhat during the experiment, from a mean of 2423 kg h^{-1} for the first series (C1) to 4114 kg h^{-1} for the last series (C2). A large proportion of the small cod was sorted out during the hauls (Fig. 6). The proportion of cod below 47 cm (MLS) was estimated to be 34.3% for the fish entering the gear. This was reduced to 12.0% in the catches without grid, and to 8.2% in the catches with a grid mounted.

The influence on the selection parameters of catches (total weight of catch, catch in numbers of cod: for codend, cover(s) or all compartments summed, catch rate: weight or numbers per hour), depth and haul duration was tested. Only catches had consistent effects. For grid and codend selection the best explanatory variables were catch rate (tonnes h^{-1}) and total weight of catch (tonnes), respectively (Table 2). For grid selection there was a negative correlation between the estimated L_{50} and catch rate. The effect of the catch size on codend selection differed between setups. There was a positive correlation between catch size and selection range in the GC setup, and between catch size and L_{50} in the C setup.

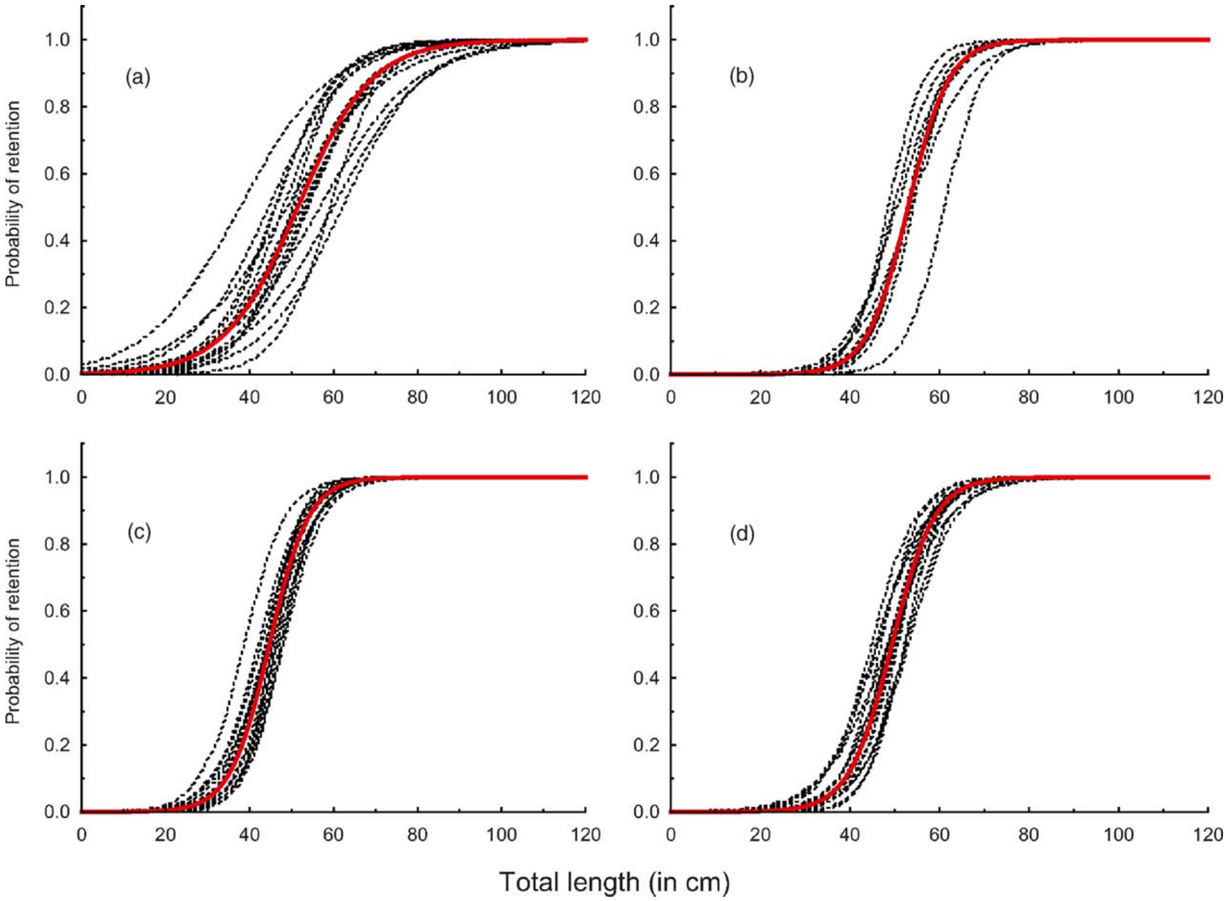

Fig. 4. Logistic selection curves for cod fitted to each single haul (dotted black lines) and the average selection curve (solid red line) for: (a) grid selection as estimated from hauls where grid and codend (mesh) selection were studied simultaneously (GC) ($n = 16$); (b) grid selection as estimated from hauls where only grid selection was studied (G) ($n = 9$); (c) codend selection as estimated from hauls where grid and codend selection were studied simultaneously (GC) ($n = 16$); (d) codend selection as estimated from hauls where only codend selection was studied (C) ($n = 18$). For selection parameters, see Table 2.

4. Discussion

When comparing selectivity between gears it is very important to keep everything but the gear differences themselves as similar as possible, in particular such factors as fish, environment and vessel. There are so many factors affecting selectivity that are impossible to control that comparisons between experiments may be useless. In spite of this, new gear variants have been introduced on the basis of such comparisons. Our study compared the selectivity of an ordinary commercial cod trawl and the same trawl with a single grid mounted. The total selection in a trawl with a grid is a product of the grid selection and the post-selection in the codend. The steepness of the selectivity curves of the trawl with and without the grid was similar, with a selection range of 9–10 cm. The L_{50} with a grid mounted was about 4 cm higher than for the ordinary trawl.

The estimated selection range was about 10 cm for both codend and grid selection. The estimated L_{50} of the trawl without grid was 49.39 cm (C setup, Table 2). The selection range of the codend is lower than that obtained by other selection experiments using similar gears, and there is also some difference in L_{50}. In an experiment with “Anny Kræmer”

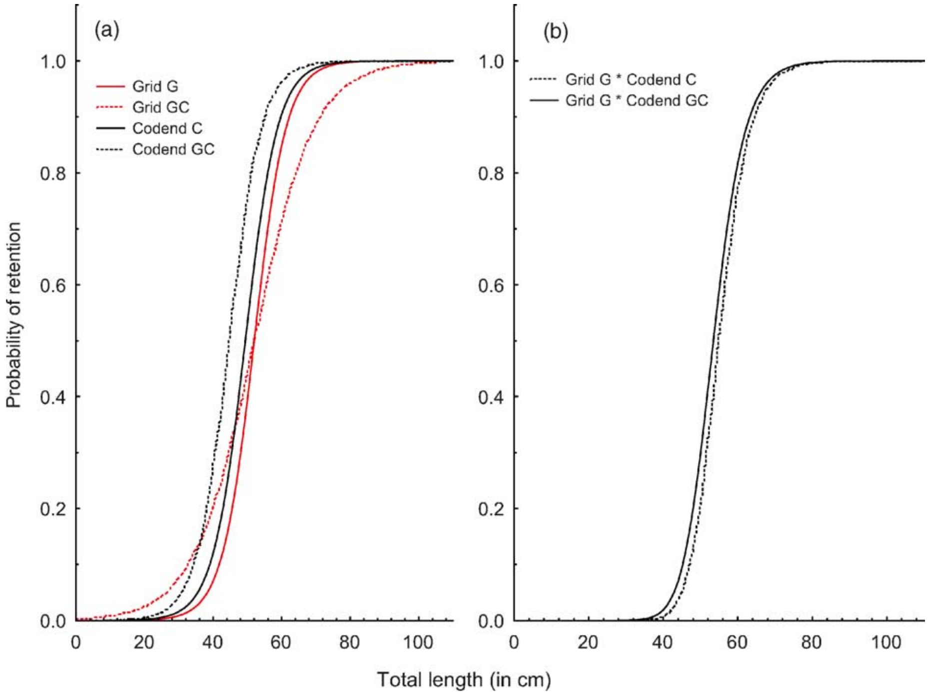

Fig. 5. (a) Grid and codend (mesh) selection curves for cod as estimated from the different experimental setups. See Table 2 (Methodology) for selection parameters. (b) The total selection of the trawl gear with a grid mounted is estimated as the product of the grid and codend selection, i.e. here the product of two logistic curves. Total selection has been estimated both from the G and C setups (grid G × codend C) and from the codend selection of the GC setup and the grid selection of the G setup (grid G × codend GC).

in August–September 1989, east of Rybackya Bank (Østbanken) in the Barents Sea, Isaksen et al. (1990) estimated the codend selection parameters for catches larger than 0.5 ton (13 hauls) to an L_{50} of about 47 cm and a selection range of about 16 cm for cod. The method of three-point-moving averages (Pope et al., 1975) was used to establish the selection curves. In an analysis of the same data, plus three hauls with catches <0.5 ton, using CC 2000 and EC software, an L_{50} of 47.1 cm and a selection range of 13.4 cm were estimated. Consequently, the L_{50} and selection range differed from our results by 2.3 and 3 cm, respectively. The codend selection in our experiment is thus considerably sharper. These differences were possibly due to the differences in codend material, as polyamid (PA) was used in 1989 whereas in our experiment a polyethylene (PE) codend was used. Valdemarsen (1987) found that the selectivity of a PE codend was at least as good as for the PA codend. However, it is also possible that differences in method (ordinary cover in 1989 versus hooped cover in 2001), time or space may have caused the differences.

The estimated L_{50} of the grid was 51.99 cm (Table 2). Two experiments which compared the Sort-X and the single grid system were carried out in August 1997 and 1998 with "Anny Kræmer" near Bear Island (Isaksen et al., 1998). The estimated L_{50} values of the single grid system were 49.7 and 53.3 cm and the selection ranges were 12.4 and 11.4 cm in 1997 and 1998, respectively. The L_{50} of our experiment lies between these values, and the selection range is about 2 cm lower. The relatively large difference between 1997 and 1998 may be attributed to environmental or fish population structure differences (Wileman et al., 1996), and shows the importance of performing simultaneous experiments when comparing gear types. It is not known how differences in fish population or environment may influence estimates of selection parameters quantitatively, but the large differences between the identical experiments

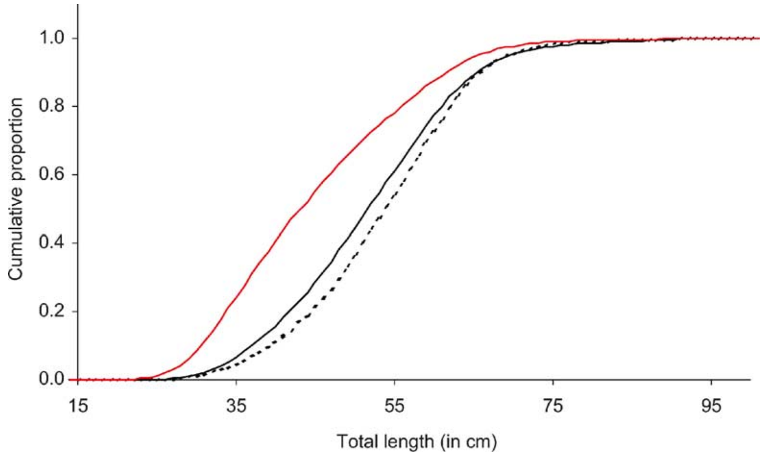

Fig. 6. The cumulative length distribution of cod entering the gear (solid red line), of cod caught in a trawl without grid (solid black line) and of cod caught in a trawl with a single grid mounted in the extension piece (dotted black line). The codend catches of the C setup were included for the estimation of the length distribution in catches without a grid, and the codend catches of the GC setup for the catches with a grid mounted. All the hauls mentioned were included for the estimation of the length distribution of the cod entering the gear. Total numbers in each length group were achieved by dividing the numbers of fish measured by the sampling proportion of the gear compartment, thus assuming equal sampling by length. The total numbers of fish were respectively $n_{\text{entering}} = 122\,952$ for the calculation of the length distribution of cod entering the gear (C and GC setup included), $n_{\text{C}} = 27\,573$ for the codend catch in the C setup, and correspondingly $n_{\text{GC}} = 34\,058$ for the GC setup.

in August 1997 and 1998 indicate that doing experiments in different periods or fishing areas increases yet further the chance of differing selectivity estimates, even between identical gears. When studying different gears it is thus essential to compare them simultaneously. Ideally, the fish girth should be used as explanatory parameter rather than length, as girth is directly related to the ability to escape through a mesh. Length is related to girth, and thus indirectly connected to selection. Girth may, however, also be influenced by condition, stomach content, sex and state of ripeness (Tester, 1935; Farran, 1936; Hamley, 1975), and it is thus difficult to assume a fixed relation between girth and length. This may be an important reason why the estimated selection parameters can vary highly between experiments carried out with the same experimental setup, gear and vessel.

The L_{50} of the post-selection in the codend with a grid mounted (GC) was estimated to be 44.68 cm, nearly 5 cm lower than for the C setup. The difference between the codend selection of the GC and C setup may have been caused by (a) possibly altered water flow in the codend with a grid mounted in the extension piece, (b) the fact that the two codends were fishing different populations and/or (c) differences in the catch size of the codend. Assuming that the fished population was the same throughout the experiment, the two codends would still be exploiting different populations, as most of the small fish in the selection range of the codend would disappear through the grid in the GC setup. The mean length of the fish would thus be higher in the population entering the codend in the GC setup than in the C setup. When fitting selection curves to data it is assumed that the fate of one fish is independent of the fate of other fish (Wileman et al., 1996), and the estimated selection curve should thus not be influenced by the length distribution of the experimental population. The estimated model parameters are, however, robust to violation of this assumption (Wileman et al., 1996). Polet and Redant (1999) and McCracken (1963) have shown that the length distribution may influence the selectivity estimates. A plausible explanation for the difference may be catch size differences, as the setup difference in theoretical L_{50} values for zero catches is reduced to about 1.5 cm (Table 2).

The steepnesses of the estimated selection curves for codend and grid selection were similar, whereas the estimated L_{50} of the codend (C) was about 2.5 cm lower than for the grid. The codend selection must,

Table 3
Total catches (kg) and catch rates (kg h^{-1}) of all species, total numbers of cod entering the gear and total numbers of cod rate (h^{-1}) for the hauls included in the selection analysis (see Table 1)

Experimental setup	No. of hauls	Catches (kg)			Catch rate (kg h^{-1})			Total numbers of cod			Total numbers of cod rate (h^{-1})		
		Mean ± S.D.	Min	Max	Mean ± S.D.	Min	Max	Mean ± S.D.	Min	Max	Mean ± S.D.	Min	Max
C 1	9	3183 ± 1302	1048	5276	2423 ± 1193	1048	3874	3000 ± 1325	949	5320	2320 ± 1393	929	5320
GC 1	10	5153 ± 3626	1391	12238	2258 ± 1788	464	5684	4499 ± 2933	1538	11254	1902 ± 1343	684	4502
G 1	9	6222 ± 5250	630	15939	3299 ± 3203	315	10626	4263 ± 3148	1473	9285	2256 ± 1908	737	6190
GC 2	6	4324 ± 2570	1722	8487	3668 ± 4536	984	12488	4762 ± 3273	1524	10075	4199 ± 5457	871	14758
C 2	9	3292 ± 1334	2130	6498	4114 ± 2275	1763	8520	2488 ± 937	1157	3748	2892 ± 1177	1388	4820

The numbers 1 and 2 below experimental setup denote the series number.

however, be compared to the total selection when using a grid, i.e. grid selection × codend selection. The total selection had an estimated L_{50} of 53.4 cm and a selection range of 9.1 cm. Could the same selection curve be obtained for a codend by increasing mesh size? Possibly, but since there may be a positive correlation between mesh size and selection range (Galbraith et al., 1994; Madsen et al., 2002), the selection range may increase for a codend with a higher L_{50}. However, other authors have found no significant correlation between mesh size and selection range (Reeves et al., 1992; Halliday et al., 1999). The possibility of achieving "grid selection" by increasing mesh size, and the relationship between mesh size and selection range, should be studied in an experiment that compares the selection of a 135 mm mesh size codend, a codend of a larger mesh size and the total selection of a trawl with a grid and a 135 mm mesh size codend. Another important aspect that, if possible, should be studied more thoroughly is the effects of catch size on selection. Any differences between codend and grid selection in terms of catch size effects should be taken into account when evaluating which gear to recommend.

The grid selection range estimated from the GC setup was nearly twice as large as with the G setup. The former result was not expected, and most certainly arose from methodological problems since the standard setup for studying grid selection gave a selection range that was comparable to other experiments. A possible explanation might be that the drag of the hooped cover behind the grid section was sufficient to raise the grid (increase the grid angle). If so, the grid would tighten up the lower panel of the trawl extension and block the passage towards the codend. Fish assemblages would press against the grid and then suddenly rush past it when the pressure was high enough. This would cause the selection range to increase. With an optimal angle the lower panel is loose enough to continuously allow the fish not escaping through the grid to pass below the grid. The results of the angle logger suggest a difference between the GC and G setups, as the mean angles were 31° and 24°, respectively. The mean angle of the GC setup was thus mainly above the optimal grid angle (25–26°).

Is the difference in selection between trawls with and without a grid large enough to recommend the use of a grid? An important question when evaluating if a new gear should be recommended or made mandatory is how the differences in selection between gear types will be mirrored in future catches, stock levels and stock composition. As introducing a new gear and seeing what happens may be an expensive way of learning and even so, completely useless for comparison, modelling is required. Our results for the two gear types can be put into an age–length structured stock model, making two separate runs: one for trawls without a grid and one for trawls with a grid mounted. If all but the selection parameters are kept constant between runs, the scenarios may be compared.

An example of a study of the effects of changing the fleet selectivity (similar to the population selectivity, as defined by Millar and Fryer (1999)) is Kvamme and Frøysa (2004), where simulations by the age–length structured stock model Fleksibest (Frøysa et al., 2002) are used. The results show that, with one fleet fishing for north-east Arctic cod, a change of just a few centimetres in the fleet's L_{50} has a strong effect on the biomass of the stock and catches.

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Appendix A

Grid (single grid system—modified Sort-V) and net characteristics of the different parts used in the selection experiment. The hooped cover consists of three net compartments, and where the characteristics are different these are given separately. D: diamond mesh, S: square mesh in term of bars, PE: polyethylene, θ: diameter.

	Grid	Codend	Hooped cover	Inside blinder
Breadth (m)	1.20	–	–	–
Length (m)	1.75	9.9	4.5, 9.0, 8.5	11
No. of meshes	–	60	80, 321, 150	195
Bars	17 round bars; θ, 12 mm	–	–	–
Bar distance (mm)	55	–	–	–
Setting angle	30°	–	–	–
Position	Mounted in an extra extension piece 14.4 m behind the end of the belly	–	–	–
Material	Stainless steel	PE	PE	PE
Mesh opening (length) (mm)	–	135 (165)	52 (56)	52 (56)
Mesh type	–	D	D, S, D	D
Netting	–	Knotted	Knotted	Knotted
Twine type	–	“Magnet” braided, double	“Redline” braided, single	“Redline” braided, single
Colour	–	Grey	Green/red	Green/red
Diameter (mm)		5	2.2	2.2
Rtex ($g\,m^{-1}$)	–	13.9	2.6	2.6
No. of open meshes round	–	48	245	180
Incl. selvedges		60	257, 253, 257	192
Selvedges (ropes)	–	2	–	–
Rope length (m)		10.4	–	–
Material		PE	–	–
Codend attachments		3 round straps[a]	–	–
		Chafers[b]	–	–
Hoops[c]		–	2	–
Diameter (m)			2.2	
Material			PE; θ, 32 mm	

[a] 50% of stretch circumference of open meshes.
[b] Mounted in lower panel.
[c] Positioned at the front and end of the square mesh part of the cover.

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